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Application of shiphandling simulation to harbour and waterway design

Part I

SUMMARY

The paper describes the problem of aiding the harbour layout design through computer simulation of ship motion. The key aspect of this support relies on treatment of the ship and the commanding pilot as a stochastic sensor testing the given harbour layout under varying environmental conditions. The role and effectiveness of the ship motion simulation in the harbour design are discussed in reference to other existing harbour design support methods.

The paper presents an example of the simulation experiment which was used for the selection of the harbour layout during planning of the expansion of Port of Callao, Peru. Such example may be used as a pattern for nautical analyses with the application of shiphandling simulation technology. The paper also evaluates the degree of fulfilment of the simulation objectives and points out the areas for further research.

HARBOUR LAYOUT DESIGN EVALUATION

The design layout of a harbour or waterway results from taking into account many requirements and constraints. Providing the manoeuvring space for the largest ships navigating in a given area – the so-called dimensioning ships - directly influences the construction and maintenance costs, navigational operation safety and harbour operation effectiveness.

The balance between the investment and operational costs and the acceptable level of navigational safety may be achieved in result of an analysis accounting for the navigational area, environmental factors, shiphandling properties of the ship and the control strategy realized by the pilot commanding the ship at a given level of navigational support. The analysis of such system requires accounting for the system dynamics and randomness associated with stochastic character of its components such as environmental conditions and human behaviour within a control loop. The main objective of such analysis is to answer whether the planned harbour dimensions are acceptable under given operational conditions. Possibility of answering such question enables to carry out optimization process of the proposed designs [1].

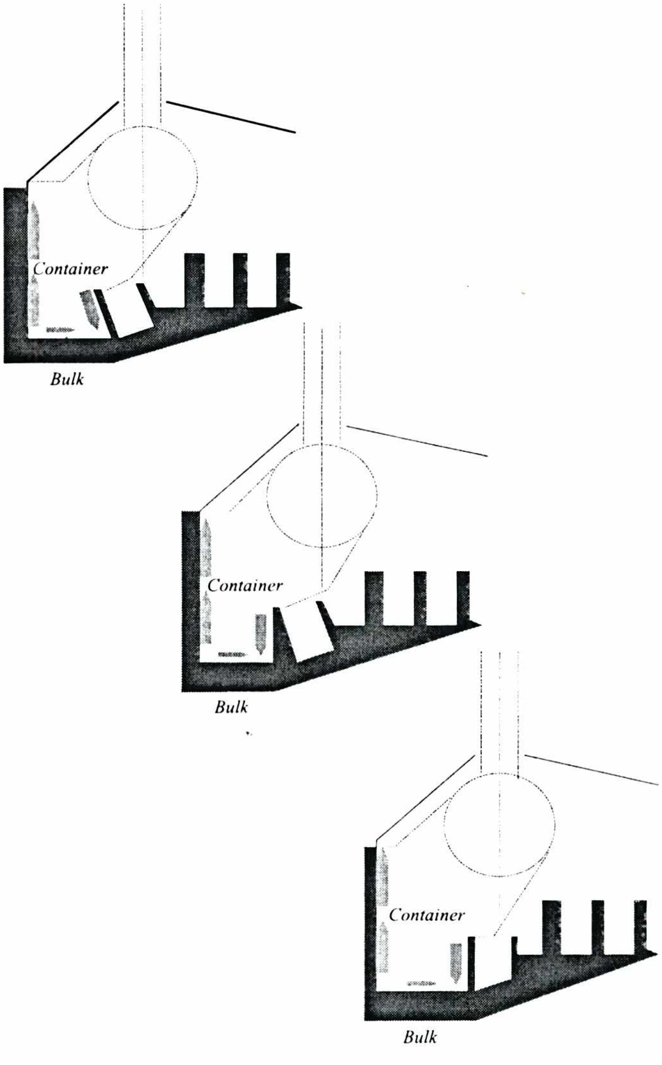

Fig.1. Considered alternatives of harbour layout design

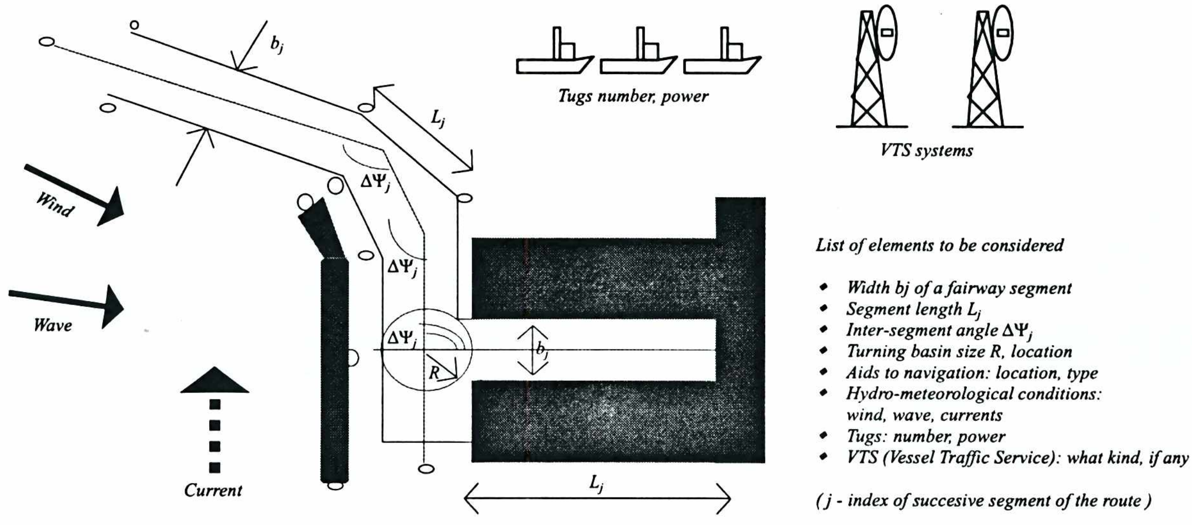

***Fig.2.** Selected elements of harbour layout, environmental factors and supporting systems studied during harbour layout assessment*

Fig.1 examplifies the design problem which consists in selecting one out of three alternative layouts of new quays in an existing harbour, to be recommended for further development. The relative location of the bulk carrier quays and container terminal quays in the harbour influences the navigational operations in it.

The design questions address :

- ➢ the required width of the approach canal
- ➢ the required width of the harbour entrance and
- ➢ the space for stopping and turning of the ships, available inside the harbour.

Fig.2 exposes the principal factors of the marine environment, harbour geometry and navigation support systems which are studied by the harbour designer. These factors should be considered first during the planning of the harbour design assessment process. Rational investigation of the influence of the factors should rely on the methods which allow to account for dynamic and stochastic character of the „harbour-ship-pilot" system.

PRINCIPAL GROUPS INTERESTED IN HARBOUR DEVELOPMENT

The assessment of the harbour layout is only a part of the expensive harbour design process. Therefore it is obligatory to consider interests and viewpoints of various groups engaged in the harbour development activity.

Below are listed the groups whose interests should be considered during harbour design phase.

Group of direct harbour users :

- ♦ investors financing the development of the harbour and its support areas
- ♦ users – e.g. captains, pilots, tug operators, navigation system operators, harbour terminal operators - who use the harbour for accomplishment of their tasks
- ♦ maritime and harbour administrations which are responsible for service and safety of the harbour.

Groups interested in the development and operation of the harbour :

- politicians
- businessmen
- other users of the harbour and adjacent areas, for example fishermen, management of bridges and roads, airspace administration, navy
- environment protection activists.

The stage of simulation analyses during the harbour design is a chance to create a platform allowing various groups of harbour users to exchange opinions and express problems.

Tab.1 lists some harbour parameters and fundamental problems associated with its usage which are significant for each of the user groups.

***Tab.1.** Harbour parameters and principal problems significant for various user groups*

Group	Harbour parameters	Principal problems
Pilots	• widths of the waterways segments • angles between successive segments of the waterway • waterway segment lengths between successive turns • size and location of the ship stopping area • size and location of the ship turning area • number, power, manoeuvring characteristics of tugs • hydrological and meteorological conditions • areas with prohibited engagement of ship main engine, thrusters; areas with restricted ship speed • navigation support system; VTS	How does the harbour help in performing the job? What is the risk of nautical operations in the harbour? Whether and how can one control the risk of nautical operations in the harbour?
Investors	• capital cost of harbour construction and equipment • time to develop the harbour • type and cost of the equipment (navigation aids, tugs, fenders) • required qualification level of users and operators • possibilities to expand the harbour • protection against the costs of an accident (insurance cost, costs of putting the harbour out of service)	What is the risk level? How to control the risk level? What are the cost of a given risk level and the cost of its modification?
Administrators	• safety of harbour operations (risk minimization) • undisturbed flow of harbour operations (minimization of congestion) • knowledge of the harbour operations risk level and costs associated with the risk (expected cost of an accident) • method of organizing nautical operations in the harbour • minimum required level of users' qualifications • standard and emergency procedures • traffic organisation inside the harbour and in its proximity • adjustment of the harbour and its operations to the existing regulations	What is the present risk level? How does the job organisation influence the risk level? How does the qualification level influence the risk level? What is the relation between the risk level and the effectiveness of harbour operations?

The applied measure of the harbour design quality is the risk level resulting from performing nautical operations in the harbour. It is calculated as the expected cost of no more than N accidents which may occur during M cycles of nautical operations in the harbour. The numbers M and N, scenarios of accidents and cost of each of them are determined by the harbour designer and maritime administration. The nautical analysis and simulation experiments can make it possible to determine the occurrence probability distributions of a given accident type t_i. The model of this situation is shown in Fig.3.

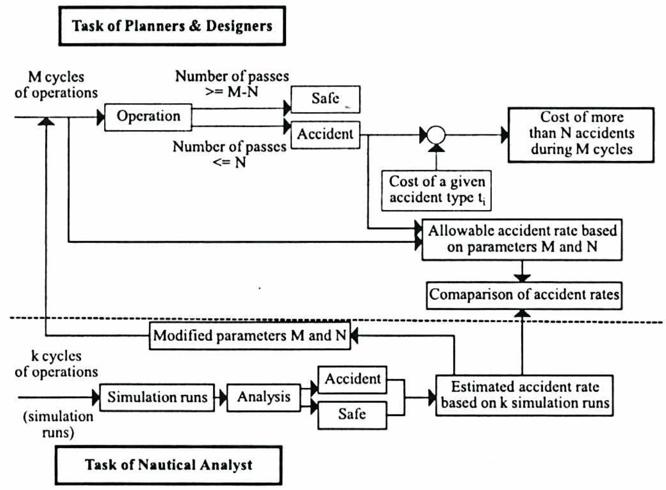

Fig.3. Measurement of the harbour design quality by using risk model

THE PRINCIPAL PROBLEM OF AIDING THE HARBOUR DESIGN THROUGH SIMULATION AND THE IDEA OF ITS ACHIEVEMENT

A ship is such a dynamic system whose responses to the control and disturbances cannot be estimated or extrapolated by means of linear methods. The studied parameters of ship behaviour significant for the harbour layout evaluation are : the ship state vector and ship control vector. The ship state vector consists of : trajectory, velocities and accelerations. The ship control vector consists of : commands for the rudder, other steering devices, main propulsion, tugs and the resulting control forces.

The harbour environment involves waves, currents and wind which are dynamic stochastic systems. The treatment of at least part of them as such a system in the model of the designed harbour allows to study a harbour model which qualitatively does not drastically differ from the real harbour system.

The significant factor is that the control process in the case of the real ships and harbour is performed by humans who play the role of control elements in the control loop consisting of ship, harbour and environment systems. In consequence, the ultimate design decisions have to take into account in some way the so-called human factor, for example, through conducting a suitable simulation experiment with a human commanding the ship manoeuvres. In this paper the human factor is understood as the necessity of making various decisions on the basis of partial and uncertain information while the decision and the execution processes are performed by a stochastic system (human) it--self, i.e. the system which responds in a stochastic manner to the same stimulation. A model of the system is shown in Fig.4.

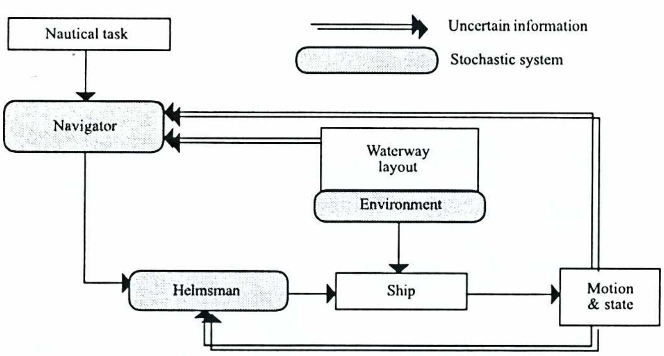

Fig.4. Control loop of performing the navigation task (featured by : uncertainty, stochastic systems, human factors)

The principal idea in question concerns the role assigned to the ship and pilot-operator which are two elements of the analyzed „environment-ship-human" system. The evaluation of the quality of the harbour layout design together with its navigation support system under given environmental conditions is performed by using the ship and pilot-operator as an integrated „probe"; the probe is stochastic due to inherent characteristics of the individual pilot. The ship-operator probe executes a navigation task under given environmental conditions - e.g. a departure from or entrance to a harbour - which generates sequences of the ship state and ship control vectors which, in turn, serve to evaluate the harbour layout and its navigation support systems. It is shown in Fig.5.

It is rather a novel look on the problem because previous methods were focused on the idea of the dimensioning ship and optional consideration of its dynamics under given conditions of harbour and environment.

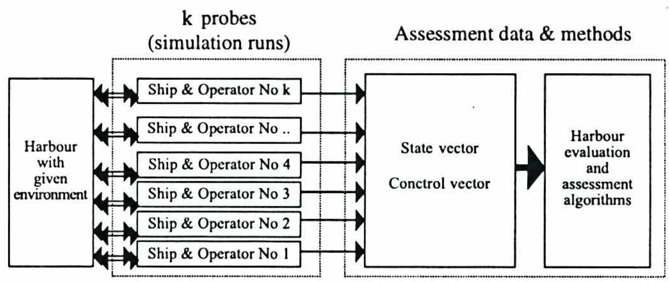

Fig.5. Evaluation of the harbour-environment system by using a ship-operator „probe"

The same approach is used when the operator is a control system (computer-based or another): i.e. if one uses an integrated ship--operator probe for the harbour assessment.

The objective of a typical analysis is the harbour layout evaluation, but not the judgement of the pilot, pilot's strategy or manoeuvring qualities of the ship.

However the elements of pilots' „imperfection" are a significant part of the simulation experiment because they represent the behaviour of trained people in the process of decision-making. Unprejudiced data from the experiment may suggest benefits resulting from the increase of the pilots' qualification level, but such suggestion is not an element of the harbour layout assessment process, instead, an advice regarding controlling the operational risk level through structured training.

EXISTING METHODS OF AIDING THE HARBOUR DESIGN

The aim of these methods is aiding the rational assessment of the harbour layout. They are tools of an analyst co-operating with a harbour designer. Which of the methods will be chosen depends on many factors; the most important ones being: the costs, access to specific technologies, experience and the kind of design questions.

The tools and methods used for aiding the harbour design are listed below :

- Design guidance based on the analysis of statistical data and studies using mathematical models of ship motion, dealing with required width of waterways, turning and harbour basins etc. The examples are publications by PIANC (Permanent International Association of Navigation Congresses) or IAPH (International Association of Ports and Harbours) as well as [2] and [3].

- „Paper" simulation of ship traffic in a harbour. They use a set of rules and regulations which describe the admissible ship behaviour in given conditions. The simulations may provide a rough estimation of the navigation space required for manoeuvring ship.
- Model tests of ship motion in the hydraulic model of a harbour. Such tests use human controlling the ship model, executed on-board or remotely.
- Computational models of ship dynamics which serve for analyzing the ship manoeuvring elements. An example is estimation of the required tug power under given conditions of quay geometry, local current, wind and waves.
- Real-time shiphandling simulators which serve for conducting experiments allowing to gather data required for the harbour assessment. There is a variety of such simulators differing with regard to their visual systems, mock-up bridge equipment and comprehensiveness of the mathematical models of simulated systems [1,4]. The real-time simulators are usually supported - - or often replaced - by the simulators which compute ship manoeuvres according to a predecided strategy. The latter systems (called the Fast-Time Simulators - FTS) allow to perform more extensive studies in comparison with their real-time counterparts. Therefore they are suitable for parametric studies, analytical studies and preparation of conditions for subsequent experiments to be performed on real-time simulators.

The tools based on computer simulation of ship motion seem to fully meet the criteria for rational methods of aiding the harbour design.

USEFULNESS AREAS OF COMPUTER SIMULATION OF SHIP MANOEUVRING MOTION

Computer simulations seem to be most helpful in such design problems where the operation risk resulting from the ship motion is significant. They are also beneficial in optimizing design solutions.

It is important that the computer simulations embrace the whole process : preparation of the simulations, realization of simulation experiments, result analysis and presentation. During this process each group of participating harbour users has opportunities to express its problems and opinions.

Classes of the problems where the simulation may be specially helpful for the harbour designer [1] are discussed below :

In the case when **the ship operation risk** is an important design factor one may determine :

- weather criteria, the risk of operations as a function of weather and hydro-meteorological factors
- the risk of operations in presence of various supporting systems (navigation aids, tugs, VTS)
- the risk of operations as a function of qualification of the personnel commanding the ship (pilot, master, officers).

In the case when **the cost and optimization of harbour design** is an important design factor one may evaluate :

- the risk of operations, costs of construction and later maintenance, associated with various designs
- the differences in ship operations, observed in various designs.

The realization costs of the simulation process may be substantial, therefore a valid question is which level of the planned investment and later maintenance costs justifies the use of a selected kind of simulation analyses. Only economical analysis of the design may answer this question. It can also appear that one needs to account for operation risk factors as well as organization and political factors, e.g. to provide objective and reliable data for the administration which approves the construction and operation of a harbour. Taking these into consideration one realises that an efficiently conducted simulation study is relatively inexpensive.

A simulation study attended by the author may serve as another example. The objective of the study was to minimize the harbour dimensions to the extent well below the dimensions generally advised, with maintained acceptable safety level of operation of the small cargo vessels equipped with lateral thrusters. The existing harbour was built to transport construction materials to the construction site of a new power plant. The harbour was to be closed just after 3 years of service. Possible reduction of the harbour investment cost was the main deciding factor of using the simulation in the case in question.

In the case when **conflicting interests are present between the groups interested in the project** one may :

- express all problems and opposite points of view
- illustrate the design problems in an understandable way for all participants of the decision-making and design process
- illustrate and examine quality of the proposed solutions or objections arisen from different points of view.

Appraised by Bolesław Mazurkiewicz, Prof.,D.Sc.

To be continued

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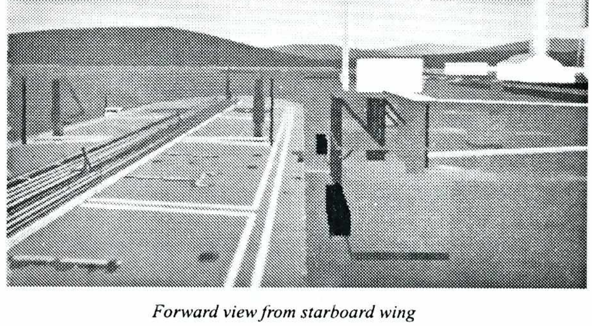

Forward view from starboard wing